Experimental Investigation with Different Inclination Angles on Copper Oscillating Heat Pipes Performance Using Fe_2O_3/Kerosene under Magnetic Field

H. R. Goshayeshi, M. Mansori, M. Ahmady, M. Khaloyi

***Abstract*—**This paper presents the result of an experimental investigation regarding the use of Fe_2O_3 nanoparticles added to kerosene as a working fluid, under magnetic field for Copper Oscillating Heat pipe with inclination angle of 0°(horizontal), 15°, 30°,45°, 60°,75° and 90° (vertical). The following were examined; measure the temperature distribution and heat transfer rate on Oscillating Heat Pipe (OHP), with magnetic field under different angles. Results showed that the addition of Fe_2O_3 nanoparticles under magnetic field improved thermal performance of OHP especially in 75°.

***Keywords*—**Copper oscillating heat pipe, Fe_2O_3, magnetic field, inclination angles.

I. INTRODUCTION

PULSATING or otherwise known as oscillating heat pipes (OHPs) are passive heat transfer systems that can offer simple and reliable operation (no moving parts and vibration-free) with high effective thermal conductivity. OHPs were first invented in the early 1990s Hisateru Akachi [1] and present promising alternatives for the removal of high localized heat fluxes to provide a necessary level of temperature uniformity across the components that need to be cooled. When the temperature difference between evaporator and condenser exceeds a certain threshold, the gas bubbles and liquid plugs begin to oscillate spontaneously back and forth. The amplitude of oscillations is quite strong and the liquid plugs penetrate into both condenser and evaporator. The heat is thus transferred not only by the latent heat transfer like in other types of heat pipes, but also by sweeping of the hot walls by the colder moving fluid and vice versa. Hence, the heat transfer mechanism between the rising liquid film along a vertical and horizontal wall is an interesting research phenomena in OPHs.

A number of investigations concerning for horizontal wall in OHP have been made from both theoretical and applied viewpoints [2]-[6]. While most of OHPs are made vertically and a large number of researcher concerning for vertical OHP [7]-[9].

Khandekar et al. [10] experimentally studied Oscillating Heat Pipe using water and ethanol as working fluids. They found that OHP does not work at horizontal orientation but operate vertically as a thermosyphon. They found that efficiency of the OHP depends on orientation, filling ratio and the inner diameter and number of bends of OHP. Phenomenon in an oscillating heat pipe is very complicated. A recent paper [11] gave a review on the working principle, research and development, effect of various parameters such as inclination angles, etc. Due to thermomagnetic convection effects and changes in magnetic properties of ferrofluid with temperature, magnetic field causes circulating flow that may lead to improvement in heat transport capability [12].

Literature review shows most studies on heat transfer in OHP have been consisted experimental measurements resulting in only a partial understanding of the effect of inclination and no paper has been published related to the effect of inclination angle of OHP with the use of Fe2O3/Kerosene under magnetic field. However, as demonstrated by [13], thermal resistances at the evaporator and condenser sections were influenced by several parameters, such as angle of inclination of OHP, inner wall can cause a large increase in heat flux for the nucleate boiling regime. Heat transfer in inclined OHP with Fe_2O_3 with kerosene under magnetic field has received little attention in the literature in accordance with vertical and horizontal OHP. In order to achieve optimum design of these systems, it is essential to analyze the heat transfer and evaluate the critical OHP angle that is the angle at which the maximum heat transfer is achieved. The objective of this paper is to study about the thermal efficiency enhancement of Oscillating heat pipe with different inclination angle using Fe_2O_3 /Kerosene under magnetic field.

II. EXPERIMENTAL PROCEDURES

Prior to charging the working fluid into the copper OHP, the apparatus was evacuated, by placing it under suction pressure of 0.1 Pa for 15 minutes using a vacuum pump connected to a three way valve. Following this initial evacuation, the three way valve was used to isolate the vacuum pump and to allow the working fluid to be charged into the OPH, see Fig. 1.

In order to simulate a number of different heat loads on the evaporator section, an electric heater connected to the electricity source via a Variac and electrical monitoring system was used. The heat input was calculated using measurements obtained the electrical monitoring system which consisted of a standard volt and current meter. Experiments are conducted with varying heat inputs of 15-90W with an increment of 90 W. The uncertainty in the

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voltage is ± 0.4 Volts and the uncertainty in reading the current is ± 0.015 Amps.

The temperatures at the various parts of the system (evaporator, adiabatic and condenser sections) were monitored using a set of type-K thermocouples connected to a portable data logging and display system. The uncertainty of measuring the temperature using the temperature monitoring arrangement was found to be ±1 K. It should be mentioned that according to our error analysis error is less than 10%. All the other geometric parameters for the OHP are given in Table I.

For the current investigation, Kerosene as carrier, Oleic acid as a surfactant and nanoparticles of Fe_2O_3 with 5 Vol.% were used. Nanoparticles of Fe_2O_3 used in this investigation have properties which given in Table II. The Fe_2O_3 nanofluid was added into the base fluid and then the base fluid with Fe_2O_3 nanofluid was continuously mixed using a magnetic stirrer. It was also sonicated with the ultrasonic oscillator for 1 hour.

TABLE I
HEAT PIPE CONFIGURATION

OHP container	Copper
OHP length	380mm
Condenser length	100mm
Adiabatic length	100mm
Evaporator length	100mm
Outer diameter	3mm
Wall thickness	1.25mm
Inner diameter	1.75mm
Liquid filled ratio	50%
Total length of OHP	4.4 m

TABLE II
PROPERTIES OF IRON OXIDE NANOPOWDER (Fe_2O_3)

Details: Iron Oxide nano powder (gamma - Fe_2O_3 - high purity)	
99.5%	Purity
20 nm	APS
40-80 m^2/g	SSA
red brown	Color
Spherical	Morphology

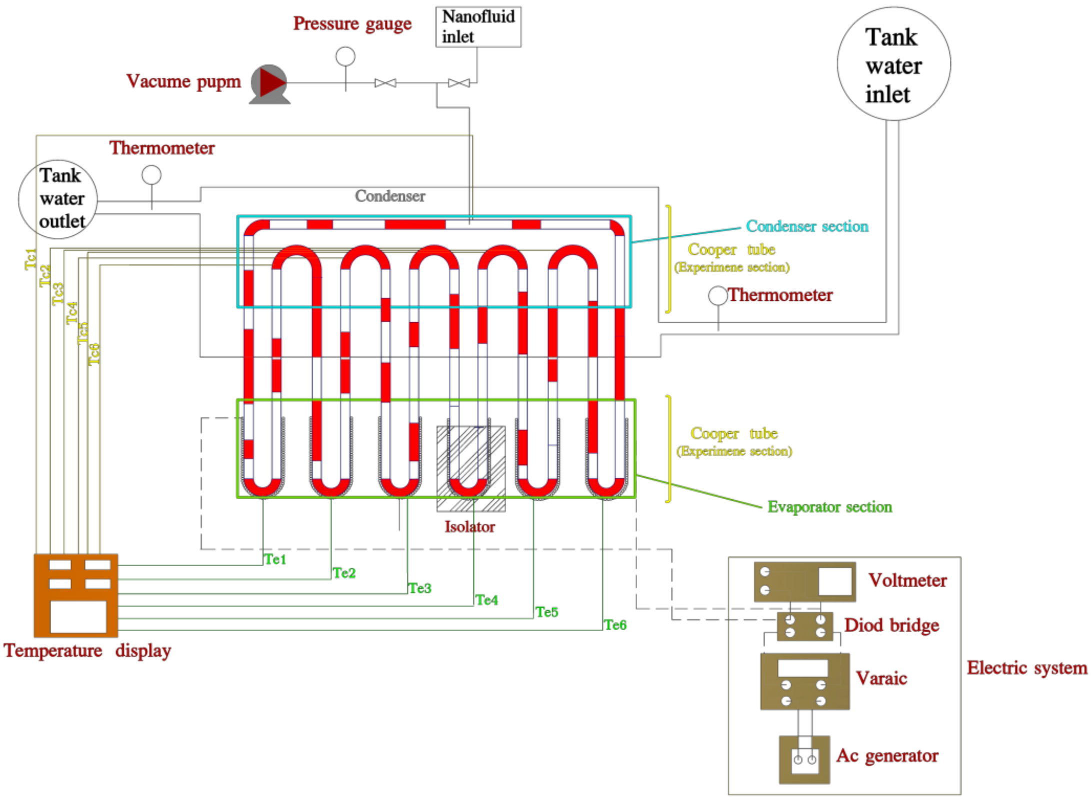

Fig. 1 Schematic of the experimental setup

III. EXPERIMENTAL RESULTS

The mean condenser temperature ($T_{c\text{-mean}}$) was calculated using the readings from the four condenser thermocouples according to (1). Due to the relatively high water flow in condenser section the temperature is constant during the experiment. The mean evaporator temperature ($T_{e\text{-mean}}$) was also calculated using the readings from the four evaporator thermocouples according to (2) and are used in this research to show the startup performance of ferrofluid used in OHPs.

$$T_{c-mean} = \frac{T_{c1}+T_{c2}+T_{c3}+T_{c4}+T_{c5}+T_{c6}}{6} \quad (1)$$

$$T_{e\text{-mean}} = \frac{T_{e1}+T_{e2}+T_{e3}+T_{e4}+T_{e5}+T_{e6}}{6} \quad (2)$$

The thermal resistance of the OHP is a measure of thermal performance, which is shown as:

$$R = \frac{T_e - T_c}{q_{in}} \tag{3}$$

where, T_e is the wall temperature of the evaporator and T_c is the wall temperature of the condenser. q_{in} is the input heat load onto the OHP which is calculated from the input current and voltage as follows:

$$q_{in} = VI \tag{4}$$

where, V is the input voltage that enter the electrical flat heater and I is the current measured by the digital multimeter.

Since the surface tension force inside the OHP pipe is dominant, an alternating chain of vapor and liquid sections is formed inside the pipe. The input heat flux, which is the driving force, increases the pressure of vapor plugs in the evaporator and the heat output decreases the pressure of vapor plugs in the condenser. So the installation angle of the OHP can be changed as shown in Figs. 2-8.

In this section, the obtained results of OHP angle effect on thermal resistance are presented. Figs. 2-8 show the thermal resistance as a function of the angle of inclination for Fe_2O_3/Kerosene without and with magnetic field. The heat thermal resistance for a particular angle of inclination, is normalized with the horizontal OHP. It is found that the critical angle is lower than 90 °. It is seen from Fig. 7 an increase in inclination angle results in rise of the heat transfer coefficient at the75°. It is speculated that application of magnetic field reduces the boundary layer thickness and improves convection heat transfer. A magnetic field pulls the nanoparticles in the magnetic nanofluid toward the walls of the evaporator and roughens its surface. This may result in improving the boiling heat transfer. The effect of Fe_2O_3 on two phase flow heat transfer enhancement may be illustrated through two reasons, the suspended Fe_2O_3 increased the thermal conductivity of base fluid and the interactions among the Fe_2O_3 and itself on one hand and between Fe_2O_3 and the inner surface of the OHP on the other hand, also, the diffusion and collision intensification of Fe_2O_3 near the wall due to increase in concentration of Fe_2O_3 leads to rapid heat transfer from OHP wall to Fe_2O_3. The influence of magnetic field of OHP in thermal resistance is shown in Figs. 9 and 10. Comparing the two figures show the in copper OHP with magnetic field the thermal resistance is lower than without magnetic field OHP especially in 75°. The reason for reducing the thermal resistance with magnetic field especially in 75° can be explained as follows. A major thermal resistance of OHP is caused by the formation of vapor bubble at the liquid-solid interface. A large bubble nucleation size creates a higher thermal resistance that prevents the transfer of heat from the solid surface to liquid. The roughness of copper surface causes the larger bubble during the bubble formation. Bubble formation and their growth are initiated by collision between upward and downward liquid slug near evaporative section. Such frequent collision generates large number of bubble which eventually merges together and forms into lengthy OHP tube size vapor plug. The reason of that can be explained because copper tube provides better thermal efficiency and higher number of pressure fluctuations with higher amplitude. The transition region can be considered as the region in which the roughness emerges from a previously unaffected viscous sublayer. It is not necessary, however, to assume that the sublayer has not been changed by the presence of a submerge roughness. Perhaps a more acceptance description of the flow near the roughness element is shown in Fig. 11.

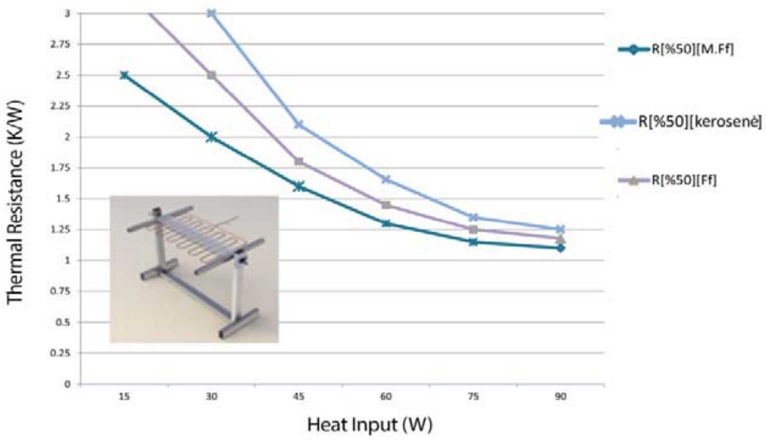

Fig. 2 Thermal Resistance of heat pipe for 0˚C inclinations

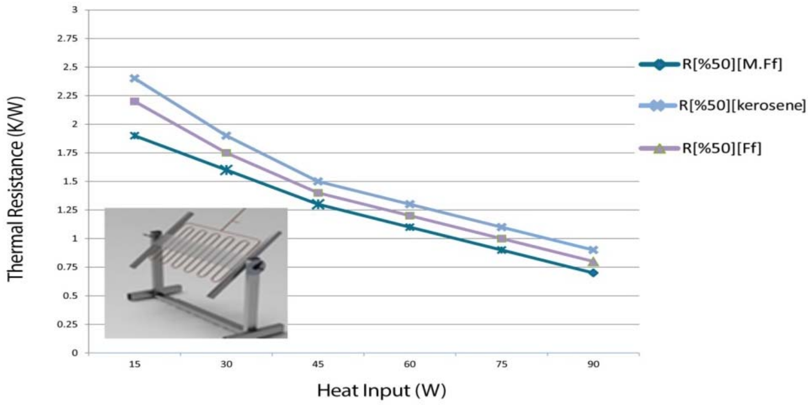

Fig. 3 Thermal Resistance of heat pipe for 15˚C inclinations

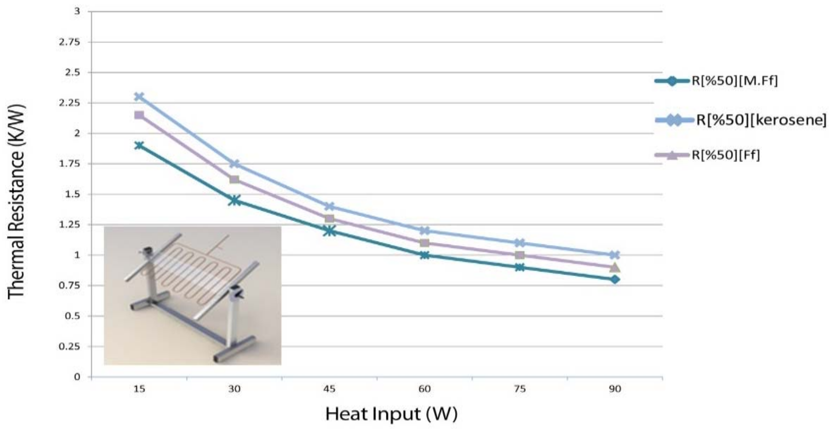

Fig. 4 Thermal Resistance of heat pipe for 30˚C inclinations

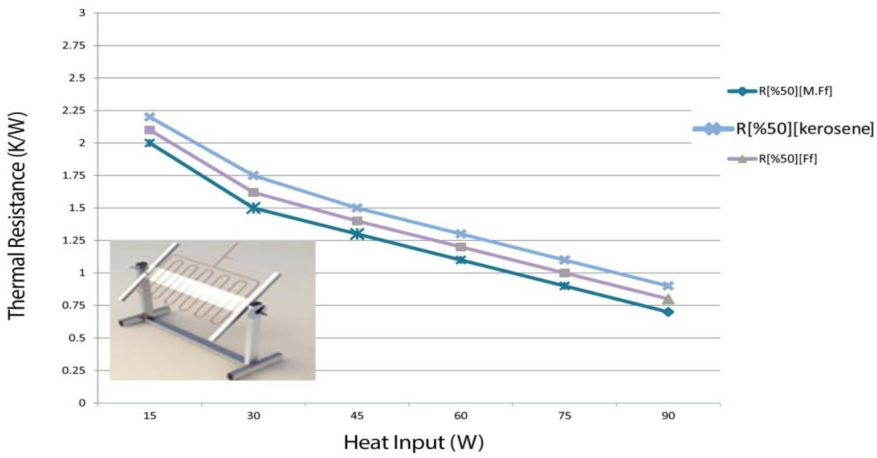

Fig. 5 Thermal Resistance of heat pipe for 45˚C inclinations.

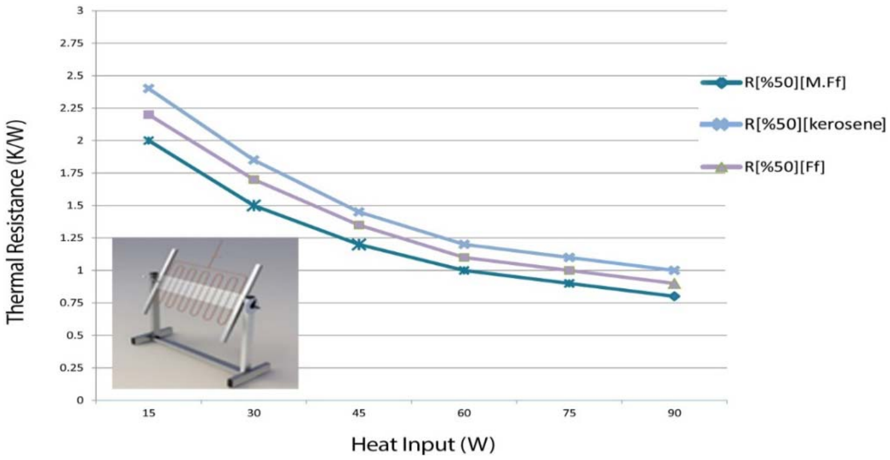

Fig. 6 Thermal Resistance of heat pipe for 60˚C inclinations

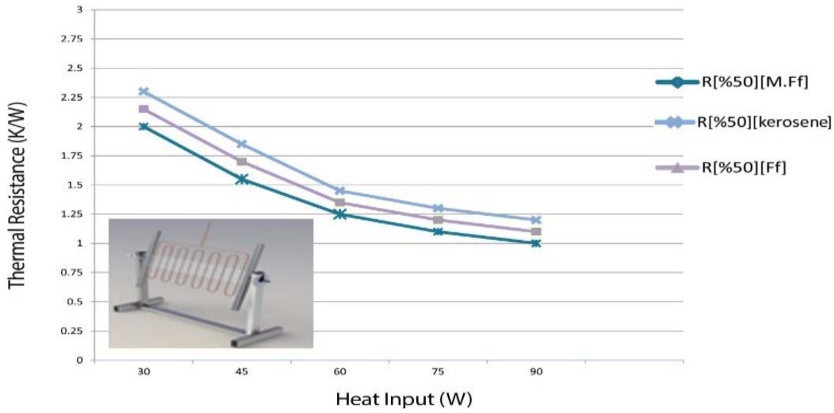

Fig. 7 Thermal Resistance of heat pipe for 75˚C inclinations

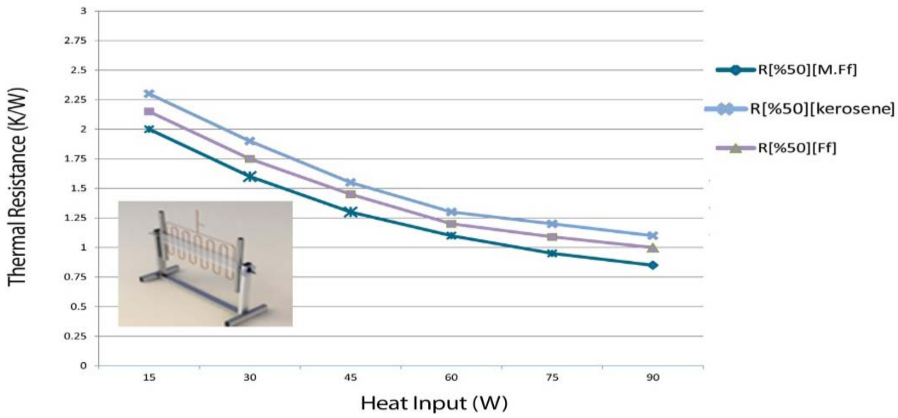

Fig. 8 Thermal Resistance of heat pipe for 90˚Cinclinations

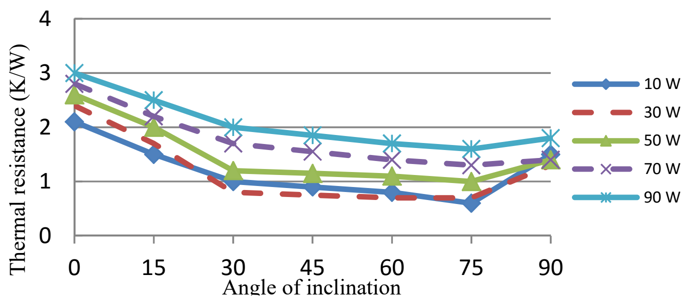

Fig. 9 Thermal resistance vs. inclination angle for ferrofluidid with magnetic field

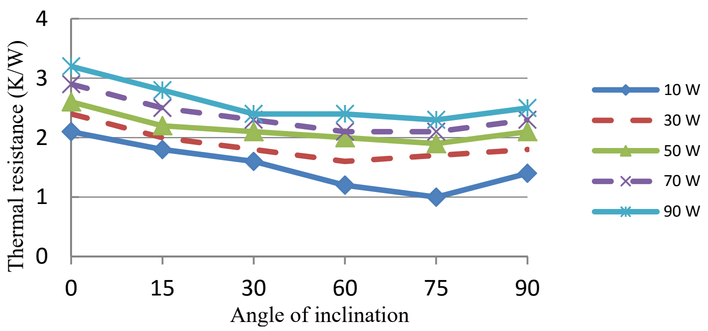

Fig.10 Thermal resistance vs. inclination angle for ferrofluidid without magnetic field

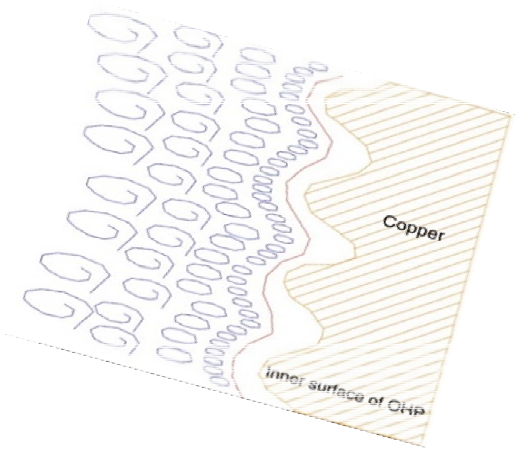

Fig. 11 Flow pattern near the rough wall at angle of 75˚

This change in the turbulence level near the rough surface would have an effect on both the momentum and heat transfer rates. Disruption of the viscous sublayer and penetration of turbulence into the valley regions results in rapid increases in the rates of both momentum and heat transfer. A greater increase in the latter would be expected, as proportionately more of the resistance to heat transfer occurs in the viscous region.

IV. Conclusions

An experimental investigation was conducted for finding the thermal efficiency for a copper oscillating pipe under different angle with Fe_2O3/Kerosene nanofluids under different experimental conditions, the optimal thermal efficiency occurred at 75 degree inclination for copper oscillating heat pipe. Comparative analysis of inclination is shown in Figs. 9 and 10. Effect of gravity, pressure differential in the system, temperature and other parameters may have influence in this fact. The inclination operating angle changes the internal flow pattern thereby resulting in different performance levels. At a certain inclination angle, the mean heat transfer coefficient of the thermo siphon reached a maximum value. From the experimental results and discussion on the performance characteristic of copper and glass surfaces arrangement in OHP, the following conclusions may be drawn:

1. The heat transfer performance of OHPs was apparently improved after using the nanofluids and this increased efficiency is higher for the nanofluid of Fe_2O_3 under magnetic field. The results indicate an increase of 16% in the heat transfer after using the Fe_2O_3 nanofluids.
2. Magnetic nanofluids such as Fe_2O_3 can decrease the thermal resistance relative to kerosene and as the result increase the thermal performance of Oscillating Heat Pipes. A 75° inclination angle relative to the horizontal axil is the optimum inclination angle for Fe_2O3 as a working fluid.
3. Angle of inclination of heat pipe also has an impact on the heat pipe performance. It encourages the condensation of liquid in the condenser section and can take more liquid flow to the evaporation. However, larger tilt angles i.e., closer to vertical position results in deterioration of

performance. It is due to faster condensate returns which affect the function of evaporation section.

APPENDIX: DATA ACCURACY

Every scientific experimental investigation involves various errors. The net effect of these errors is to cause a difference between the actual values of parameters and their values measured by the observer. Therefore, there is always an attempt to evaluate the existing errors in an experiment. In all the experiments, the heat power to the system has been calculated directly from the measured electrical power to the system. The error analysis has been performed with the method expressed by [14]. After carrying out a detailed error analysis and considering the accuracy of individual measurements, it was made clear that at low heat fluxes, the maximum measurement error in the input heat flux is less than 5.7%. When this heat flux increases, the error lowers to %2.4. According to this error analysis, it can be concluded that the measured quantities are appropriate.

As the result uncertainty can be shown as:

$$\frac{\Delta Q}{Q} = \left[\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta I}{I}\right)^2\right]^{1/2}$$

The uncertainty in the thermal resistance depends on the applied heat input and temperature difference between the condenser and evaporator ends.

$$\frac{\Delta R}{R} = \left[\left(\frac{\Delta Q}{Q}\right)^2 + \left(\frac{\Delta(\Delta T)}{\Delta T}\right)^2\right]^{1/2}$$

The heat transfer coefficient h, is calculated by:

$$h = \frac{q}{\Delta T}$$

The uncertainty of heat transfer coefficient is given below and the parameters are heat flux and temperature difference of surface and vapor temperatures.

$$\frac{\Delta h}{h} = \left[\left(\frac{\Delta q}{q}\right)^2 + \left(\frac{\Delta(\Delta T)}{\Delta T_v}\right)^2\right]^{1/2}$$

The efficiency of the Oscillating Heat Pipe can be defined as the cooling water supplied to the condenser divided by heat input.

$$\eta_{th} = \frac{Q_c}{Q_{input}} = \frac{\dot{m} C_{pw} T_w}{Q_{input}}$$

The uncertainty in the thermal efficiency can be calculated by:

$$\frac{\Delta \eta}{\eta} = \left[\left(\frac{\Delta Q}{Q}\right)^2 + \left(\frac{\Delta \dot{m}_c}{\dot{m}_c}\right)^2 + \left(\frac{\Delta(\Delta T_w)}{\Delta T_w}\right)^2\right]^{1/2}$$

The uncertainties in thermal resistance, heat transfer coefficient and thermal efficiency are 0.329%, 0.318%, 0.410%, and 0.312%, respectively.

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